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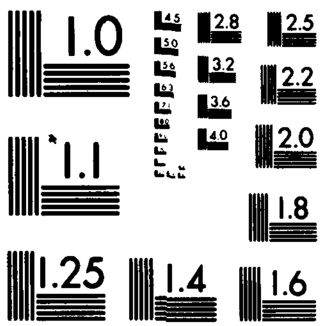

MICROCOPY RESOLUTION TEST CHART

HEURISTIC INFORMATION PROCESSING AS IMPLEMENTED IN TARGET MOTION RESOLUTION ANALYSIS OF RADAR DATA

*JOHN N. HYNES, MR.
DAVID S. JIMAREZ, MR.
US ARMY WHITE SANDS MISSILE RANGE
WHITE SANDS MISSILE RANGE, NEW MEXICO 88002

INTRODUCTION

The US Army White Sands Missile Range (WSMR) has been conducting a research and development program for the production of precise trajectory parameters, center of gravity motions, and target events in support of a number of range customers. Some of the more important of these customers have included the Multiple Launch Rocket System (MLRS), Patriot, DIVADS, and Copperhead.

The process is called Target Motion Resolution (TMR) and is based on post-flight processing of the doppler-shifted returns from coherent C-band instrumentation radar systems. Since 1974, Mark Resources Incorporated, Santa Monica, California, the contractor for the development, has been extending the basic theory and producing procedures and software. They have also been implementing the developments on an interactive graphics minicomputer system operated by government data technicians at WSMR. Of all WSMR personnel associated with the development and implementation of TMR, data technicians have probably felt the greatest impact. Being a highly specialized technology, TMR requires both a large amount of processing and a fairly high level of knowledge in areas such as radar theory, digital signal processing, FM theory, spline functions, computer science, and interactive graphics minicomputer operation. Data technicians, by contrast, generally have a high school level education and are accustomed to submitting a prefab deck of cards, along with a radar tape, and awaiting results. Naturally, they have resisted the multistep, interactive graphics TMR reduction requiring highly technical interaction between steps.

In 1979, WSMR began a new effort aimed at improving the complex interface between the technician and the TMR reduction process. Studies performed included investigation of heuristic algorithms and knowledge

based system (KBS) technology by the Integrated Sciences Corporation (ISC), and human factors by the Army Research Institute (ARI), Human Factors Area. Results revealed that the system contained an inadequate level of "function" development for efficient use by data technicians. System response needed improvement, processing needed simplification, function keys were needed to facilitate interaction, and cumbersome manual procedures needed automation. In the months that followed, hardware was implemented and processing procedures simplified to meet the needs identified. Two particularly cumbersome manual processes were also significantly improved through an agreed upon heuristic approach. The methodology utilized involved developing a working model of the expert analyst's approach by observing him solve the particular TMR processing problems, generating the associated protocols used, and then placing this intelligence on the machine. The two new processes involved the development of specialized spectral trackers primarily for use in extracting spin frequency information from the MLRS. Basic measurement principles and the general TMR reduction process will be described before presentation of these trackers. Conclusions about their effectiveness compared to procedures used earlier will then be made.

MEASUREMENT PRINCIPLES

AN/FPS-16 and AN/MPS-36 C-band instrumentation radars, traditionally, make radar range and angle measurements by transmitting a pulse of energy to the target and measuring time and direction of arrival of the reradiated pulse. The coherent radars can also make average range rate measurements by tracking the relative doppler shift of the reradiated pulse with respect to the carrier signal reference (1). Unfortunately, these measurements produce only a rough target location and tell nothing about center of gravity motions. Further, the range rate trackers often prove unreliable due to problems such as glint, scintillation, and clutter. The problem of crude target location is inherent to the gross measuring stick used to make the measurement (i.e., a 1/4 microsecond pulse covers a range of about 75 meters), and precision has often been demonstrated to be only 5 to 10 meters. TMR processing, by contrast, utilizes the radar wavelength as its basic measuring stick, about 5 centimeters for a carrier frequency of about 5.8 GHz. With this type of precision, it is possible to measure the movement of one part of a target with respect to another to obtain center of gravity motions (2). In trade for the finer precision, however, the processing becomes complicated having to deal with modular phase measurements and the fact that each return is a combination of the returns from all scattering centers. The modular phase measurement causes a range ambiguity every 1/2 wavelength or about 2.5 centimeters, considering the two way path a pulse must travel. The range rate ambiguity, roughly 8 meters/second at 320 pulses per second, is obtained by dividing the range ambiguity by the time between pulses. Similarly computed, the acceleration ambiguity is about

2560 meters/second^2, which is generally large enough to cause little problem. Range and range rate ambiguities, however, require joint processing with the usual crude range data for their resolution. Fourier analysis is then used to map the average, combined returns from all scattering centers into their average, individual returns over a period of time. Fourier analysis of successive time segments would then produce a doppler history, or a history of the individual scattering center velocities, relative to the radar.

Trajectory compensation begins by spline approximating the usual unambiguous range data, and subtracting this information from the phase data. This removes the gross translational motion from the phase data, leaving only residual translational wander and center of gravity motions. Next, spline approximation and removal of the residual translational wander leaves only center of gravity motion. Precise approximation and removal of the center of gravity motion then gives the desired alignment to a particular scattering center, allowing for relative spin frequency measurement. Figures 1 through 4 show representative doppler history plots of raw, range compensated, residual translational wander compensated, and precisely aligned phase data. In interpreting each plot, a peak's position in a spectrum indicates the radial velocity of the scattering center it represents. The portion of the plot left of center represents increasing velocity of a scattering center moving away from the radar, and right of center represents increasing velocity of a scattering center moving toward the radar. Should a velocity ambiguity occur, a peak would alias, or run off the end of a line, and appear wrapped around on the other end.

BASE SPECTRAL PEAK TRACKING

Precise alignment of data, as seen in figure 4, requires alignment of figure 3 data to within ±20 Hz of zero doppler. Before the alignment process, the data would be low pass filtered in this interval to eliminate possible interference from spin frequency returns. Unfortunately, a ±20 Hz alignment is not always possible by a vernier spline adjustment of range compensated data, and requires an analyst to manually intervene. WSMR, ISC, and ARI collectively agreed that work under the heuristic approach mentioned should be initiated to automate this process (3). The problems that had to be overcome, as seen in figure 5 to 8, fall into four main classes: 1) Clutter, 2) desired return amplitude fading, 3) large spin frequency amplitudes, and 4) velocity ambiguities, seen as aliasing or wrap around in the doppler history plots. Figure 5 shows an example of clutter, considered here to be a broad class of undesired returns, appearing at any frequency, singularly or clustered, with amplitudes often larger than the desired return. Figure 6 shows how target orientation to the radar and destructive interference from other returns can cause relative fading or cancellation of the desired return.

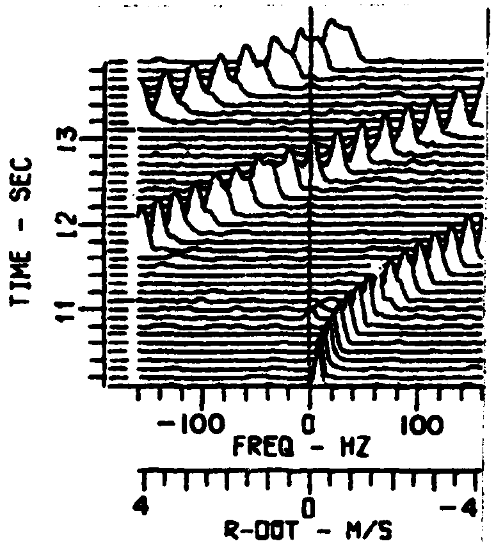

Figure 1. Raw data.

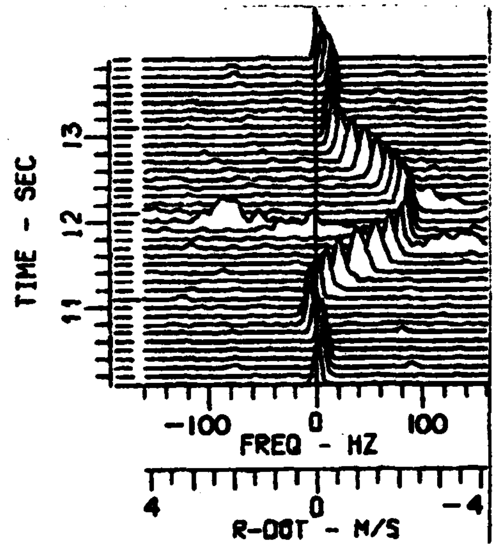

Figure 2. Range compensated data.

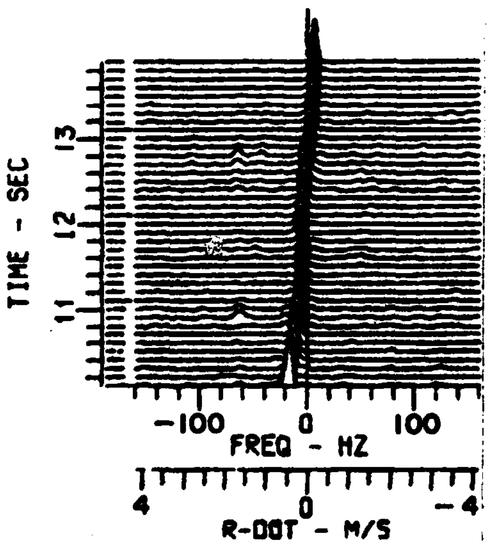

Figure 3. Translational wander compensated data.

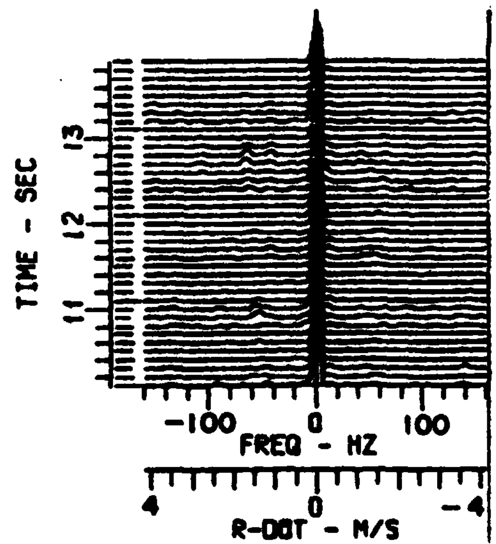

Figure 4. Precisely aligned data.

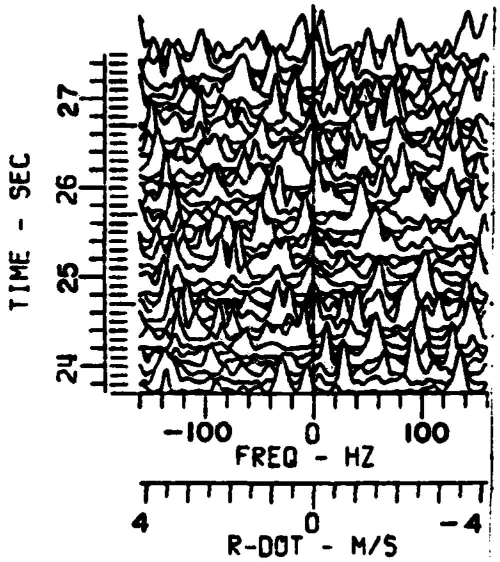

Figure 5. Clutter

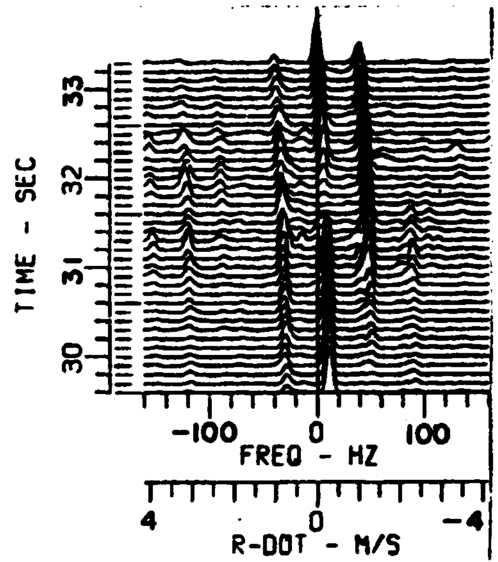

Figure 6. Desired return amplitude fading.

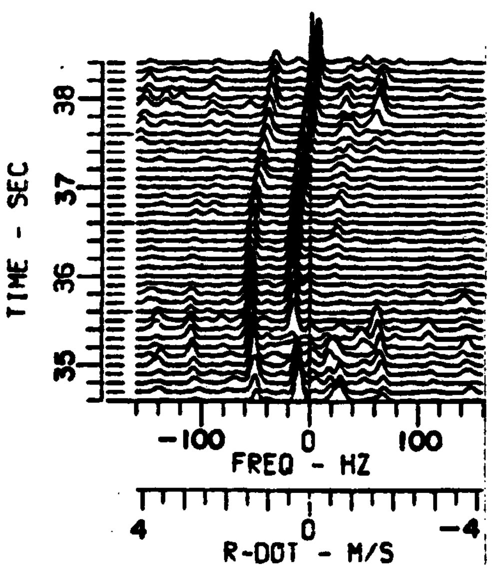

Figure 7. Large spin frequency amplitudes.

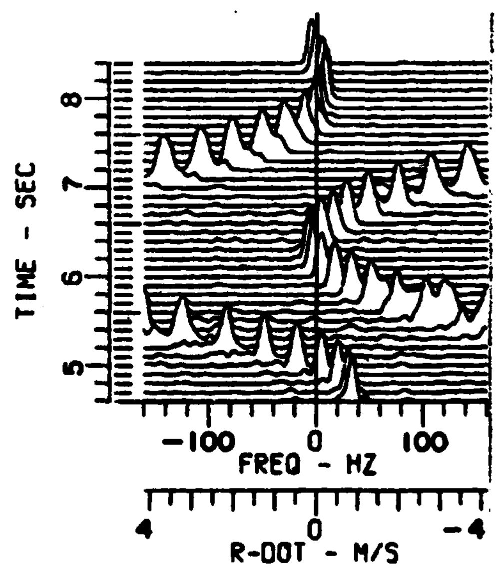

Figure 8. Velocity ambiguities.

Figure 7 shows the effect of large spin frequency returns even when the desired return does not fade. Figure 8 shows an example of velocity ambiguities, due primarily to an inadequate range compensation. Velocity ambiguities usually indicate large acceleration components, where the velocity of a particular scattering center, as indicated by its position in a doppler history plot, changes significantly as a function of time.

Early, batch mode efforts to align data with these problems were excessively long, generally taking as much as 2 days. In this process, two college level, trained analysts would manually identify and measure the doppler shifts of the desired returns and develop the parameters for spline adjustment before the computer was even used. An interactive graphics approach significantly improved the process, wherein an analyst could then align the data by interacting with plots of doppler history and the largest peak locations for the respective spectra. Figure 9 shows examples of such plots for an MLRS flight with a particularly bad range compensation, exhibiting all four classes of problems. Using the doppler history for reference, the analyst would attempt alignment by overlaying the plot of largest peaks with breakpoints of a linear spline approximation. Without the aid of the doppler history plot it would often be difficult to tell if the largest peaks were the desired ones. The option to correct for velocity ambiguity discontinuity in the plot of largest peaks was controlled by a heuristic. If a velocity ambiguity occurred, the distance between desired peaks before and after ambiguity generally differed by more than half the entire interval. Successive peak locations would then be adjusted by an entire interval to preserve continuity. Such a heuristic, however, often causes problems in that the wrong segment may be adjusted or, as seen in the following example, in that it is susceptible to large undesired returns.

In attempting to align the data of figure 9, an analyst would use the continuity option since velocity ambiguities occur at about 5.5 and 7 seconds. The doppler history would be recomputed and the plot of largest peaks redrawn, as seen in the right half of figure 10. Unfortunately, use of the option caused false ambiguity jumps at 21.3 and 25.7 seconds due to large clutter returns. A reasonable attempt to spline adjust, in spite of the false ambiguity jumps, would be indicated by the linear spline superimposed on the plot to the right in figure 10. The corresponding phase adjustment is seen in the doppler history to the left. Faced with the alignment being outside ±20 Hz, the analyst may regenerate the original plot in figure 9 and try again. The corresponding attempt, and the resulting failure, would probably be as indicated in figure 11. Again faced with inadequate alignment, the analyst may try reprocessing either or both cases, or even splitting both splines and combining the better halves of each. In any event, a proper alignment would require a trained analyst, as opposed to a data technician, and a considerable amount of time.

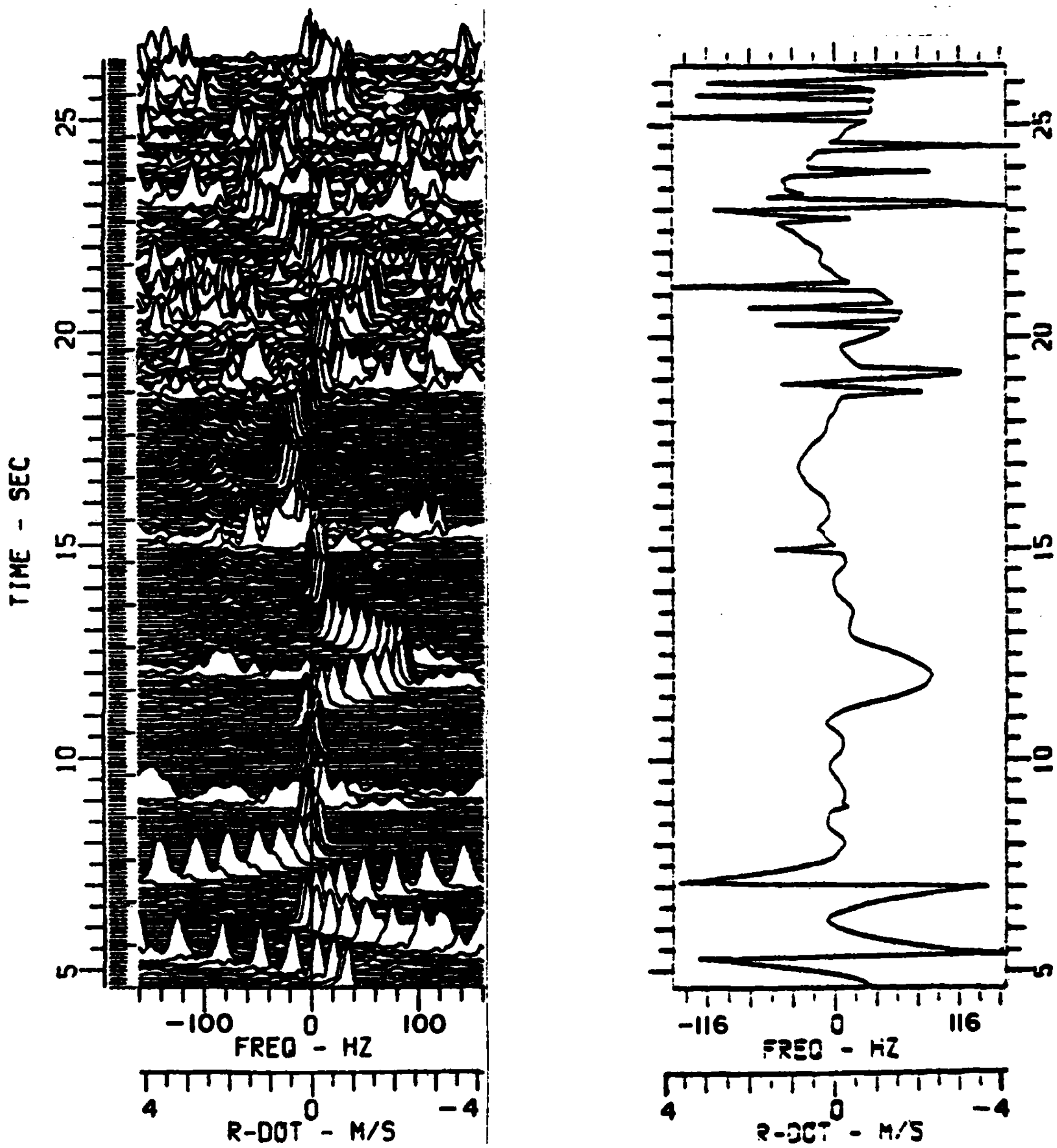

Figure 9. Unacceptable trajectory compensated data.

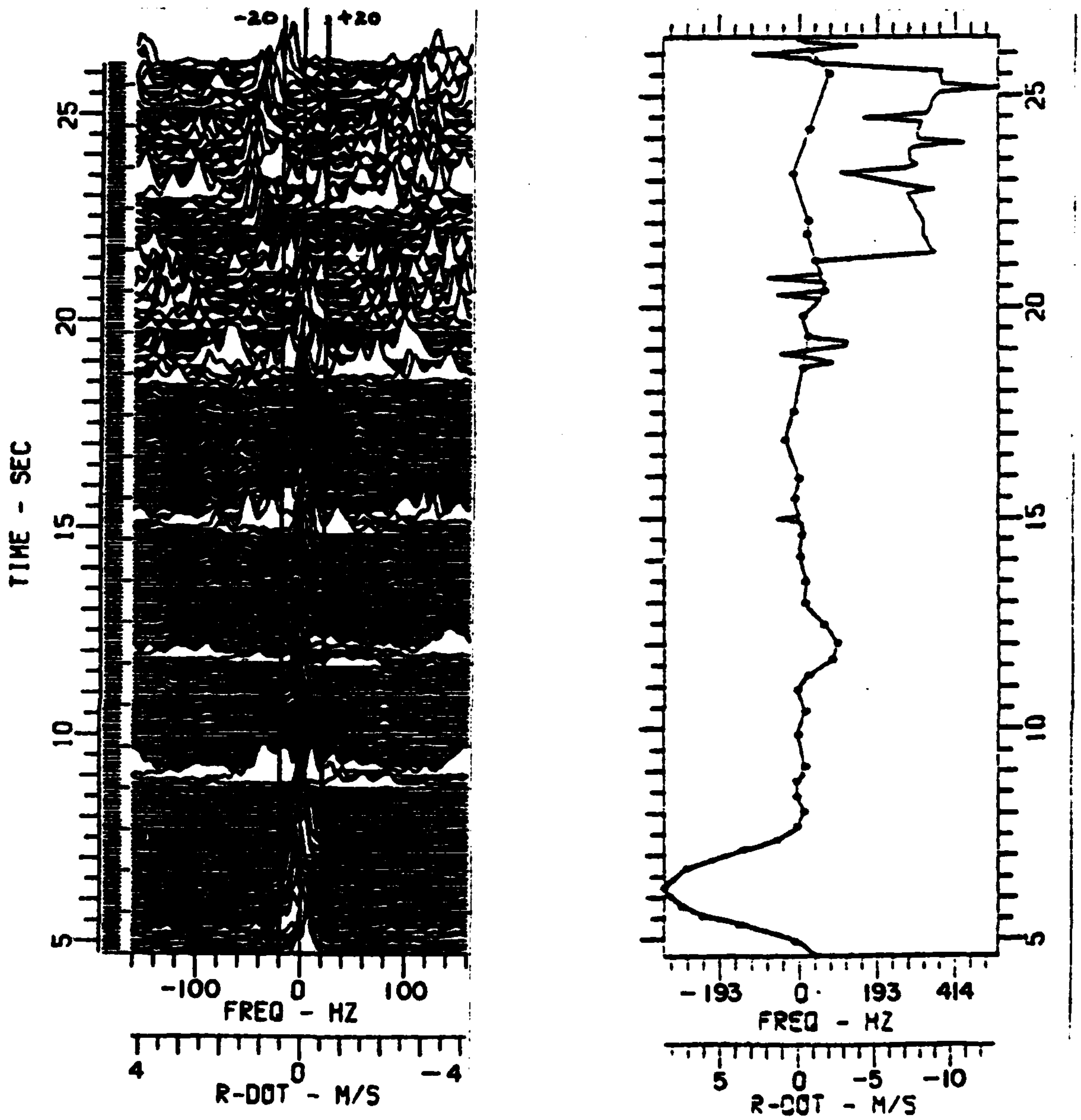

Figure 10. Example 1 of interactive graphics adjustment.

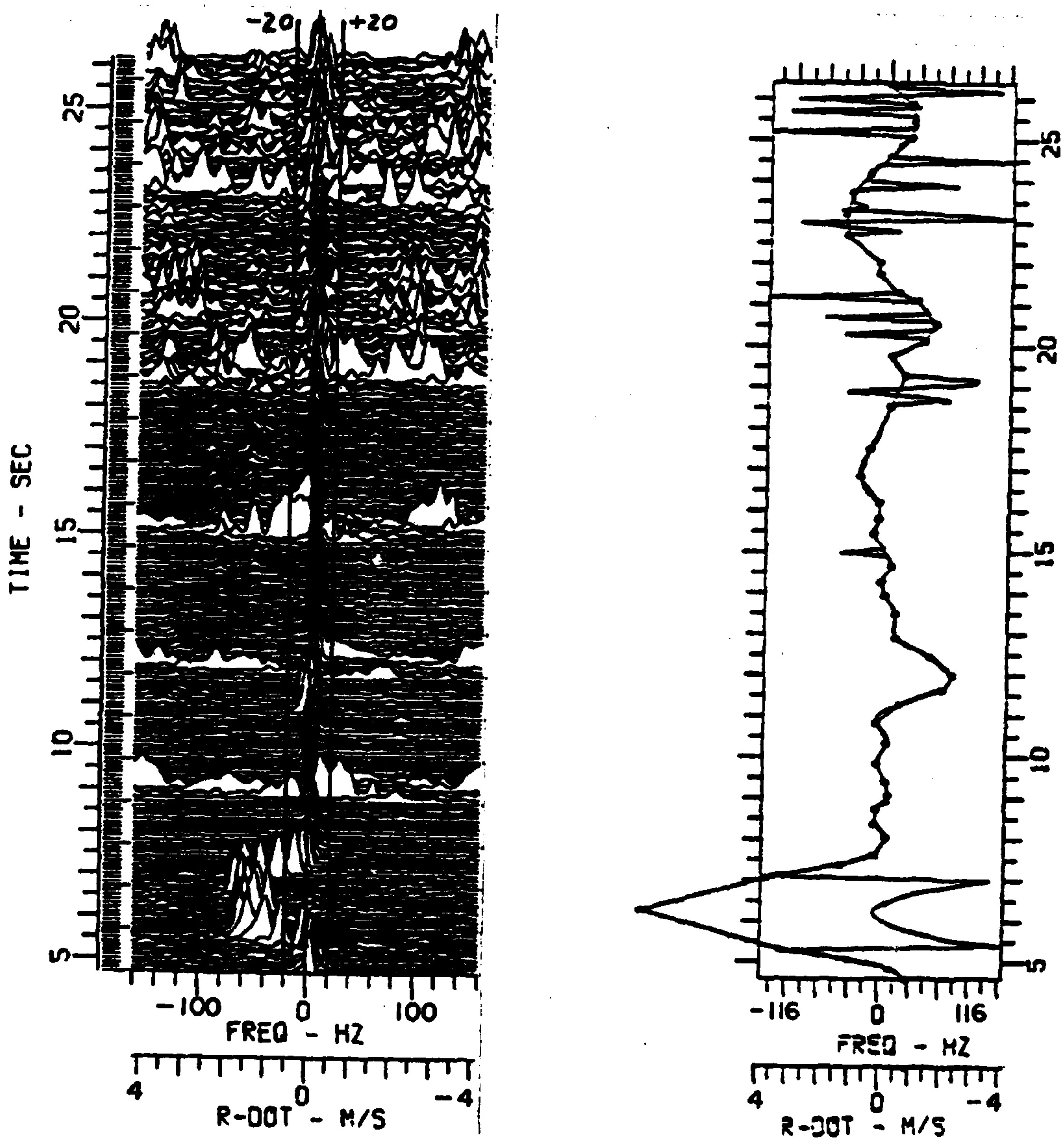

Figure 11. Example 2 of interactive graphics adjustment.

The methodology used to automate the process began with observing a well trained analyst perform the alignment. Generally, what an analyst would do is locate the desired peaks and follow their trend through the data in a windowed fashion. In observing this process, several important considerations were noted: 1) If peaks ran off one side they were sought on the other, 2) fading was controlled by following the general trend until peaks reappeared, 3) large noise returns in the area of the general trend would be identified and ignored, and 4) when large spin frequency returns were noted, care was taken to keep the search window between them. It was further noted that these considerations vary, being dependent upon technical knowledge in the areas mentioned as well as physics of the flight. The first step taken toward automating the process was reducing this variability by standardizing the parameters for the production of doppler histories. Now the problem became analogous to a state-space search (4), where the desire was systematically discovering the doppler history of a particular scatterer. With row elements acting as nodes, the analyst's heuristics could be used to form a generator function to calculate candidate successor nodes, and an evaluation function to determine their likelihoods of representing the desired scatterer's return. The search would resemble a tree search in that only the start node has no parent, and that every other node has only one parent and is a descendent of the start node. This paper will refer to goal nodes as peaks in the context of returns from the desired scatterer.

Several heuristics were used in the development of generator and evaluator functions to automate the analyst's tracking considerations. First, returns from the base of the MLRS should be used for alignment since, on the average, they are the strongest axially symmetric returns by virtue of radar orientation. Second, the short segments of peaks generally extrapolate linearly into close proximity of the next peak location. Third, most acceleration components occur near the beginning of data, where spin returns are not as noticeable. Fourth, large spin returns, especially in conjunction with faded base returns, primarily occurred later in the better radar tracked, ballistic portion of the flight. What developed was a function that generated candidate peaks by extrapolating the center of a window which widened or tightened, as acceleration components increased or decreased, respectively. Extrapolation was by a linear least squares fit of the last few peaks, where the slope of the fit controlled window width. Window parameters were also adjusted to fall within large spin frequency returns during the ballistic portion of the flight. Next, the evaluator function selected the peak as the element with the largest magnitude in the window. As the interference of large clutter returns within these windows was generally random, infrequent, and in small numbers, the analyst's ability to ignore them on the basis of general trend was implemented as a median smoothing function (5). As false ambiguity jumps were no longer a problem, since the window never spanned half an interval, all that remained was compensation of the

proper segment when a jump did occur. This was controlled by the heuristic that the ballistic portion of the flight should have the best radar track, and therefore the best range compensation. This was implemented by adjusting all previously tracked segments when velocity ambiguities occurred before mid-flight, and adjusting subsequently tracked segments when velocity ambiguities occurred after mid-flight.

Together, the heuristic functions proved quite successful, as is seen by the adjustment in figure 12 of the corresponding figure 9 data. The procedure now takes seconds rather than 1/2 to 1 hour, can be run by an ordinary data technician rather than a trained analyst, and maintains better than 95 percent reliability in routine reductions. Further, the analyst has the option, while using the procedure, to change parameters necessary to gain the required alignment on similar data with differing anomalies.

SPIN FREQUENCY TRACKING

Spin frequency tracking generally encounters the same classes of problems as base return tracking, but with different variations. Now, many peaks, or goal nodes, can exist per line as multiples of four times the spin frequency are present. Further, these multiples can independently fade for long periods of time, or interfere with one another because of higher multiples wrapping back around onto lower multiples. Multiples of four are primarily due to the four-fold symmetry of the missile's fins, with most of the intermediate lines cancelling because of opposing doppler returns. In order to clearly display the multiples in a

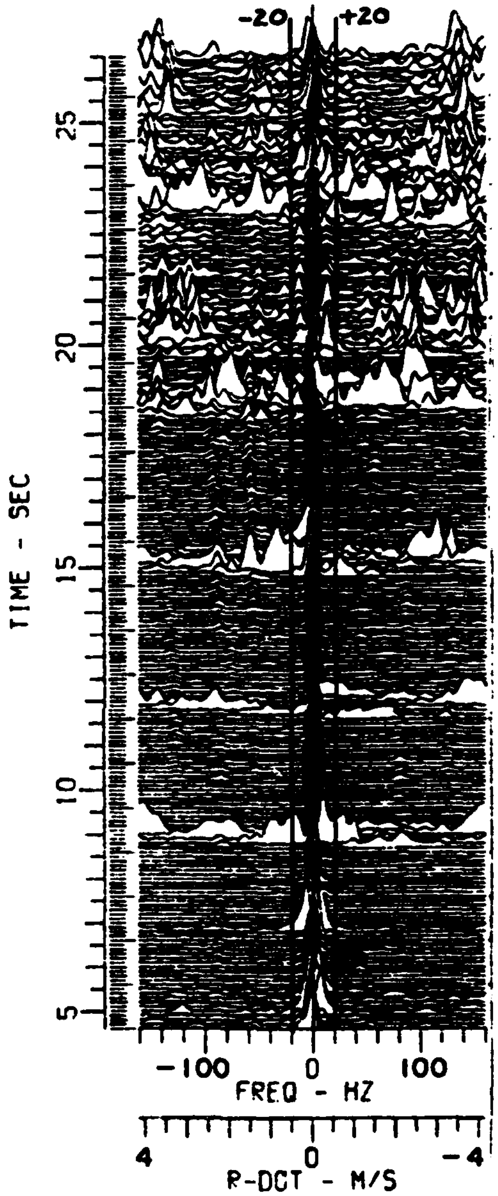

Figure 12. Main spectral peak tracker adjustment.

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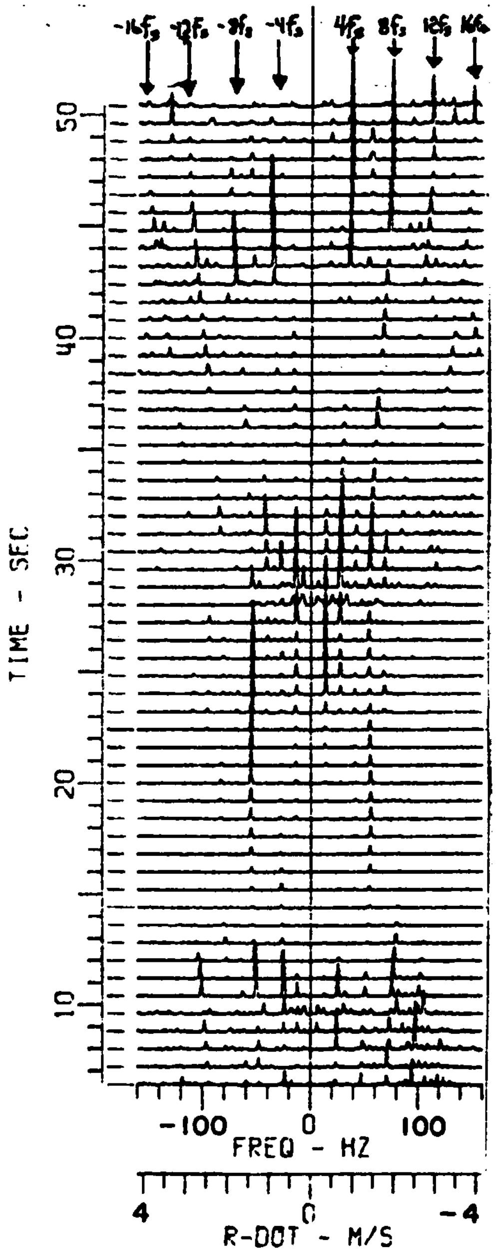

Figure 13. MLRS spin doppler history.

hat part or all of this information is available even though a numeric nput is requested. Statistics on the current reduction are also vailable to the user, and are used to update the permanent statistics if he user feels the process was successful. Finally, the expert user nterface duplicates the user interface except for the capability of ltering the expert knowledge modules.

The cognitive engine is the active processing element containing the enerator and evaluator functions as well as the inference and reasoning lgorithms that interact with the current problem state. Candidate spin eturns are first generated as the largest returns in a given line, where he number generated is generally equal to the number of spin traces that ɔ not alias. This function is based on the heuristic that most spin ultiples present will probably constitute the larger returns, with most ɔwer contained in the lower, unaliased multiples. The evaluator function hen works like the analyst, using a small search window to locate a spin eturn. The window center is first extrapolated to the expected areas of he largest multiples, on each side of the spectrum, and then to succesive lower multiples if a peak is not found. Problems of clutter, liasing, and finding no peaks are then handled interactively through the se of the inference and reasoning algorithms. For example, if no peak or ore than one peak is found, tracking is halted and the user is made aware f the problem and the location. The user then has the option of allowing he process to make its best guess, based on the current state of the roblem, or to enter an overriding location. Statistics are also compiled n the number and nature of such interruptions for the purpose of later dvising the user in the event results are unsatisfactory. For instance, inding multiple peaks more often than not finding peaks might indicate hat a smaller search window would have greater success. In the event a ata technician has exhausted the resources of the process and is still nsatisfied, presentation of results and statistics to a trained analyst an usually gain an expeditious solution.

The new process contains many other heuristic based features used by rained analysts in processing spin information, including forward, backard, and segmented processing and extraneous frequency rejection. While t is too lengthy to discuss them all here, it is worth noting that ollectively they have made significant advances in obtaining spin nformation for the MLRS. The process successfully tracks the spin requency through fading, clutter, and the aliasing of higher spin ultiples back onto lower spin multiples with better than 90 percent eliability in routine reductions. Primarily, this was achieved by lacing the techniques of TMR analyst into the process and at the mmediate disposal of the data technician. The analysts' capability to pdate the expert knowledge modules also reduces future reduction time by aking data technicians even less dependent on their presence.

*(multiple launch rocket system

CONCLUSIONS

The two new processes for MLRS* base and spin frequency tracking have made significant advances in the quality and speed with which data are produced for that project. Routine processing of these parameters can now be performed, using data technicians, in less than a tenth of the time formerly required by a trained analyst. While developed primarily for the MLRS, each process also has applicability to similar classes of targets, thus reducing later developmental efforts. In the future, developments in this area will continue, becoming more sophisticated and having wider applicability, helping to support the increasingly demanding test and evaluation needs of our new weapons systems.

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